RADIATIVE TRANSFER IN SEAGRASS CANOPIES

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LONG-TERM GOAL

The overall objective of this study is to develop models of radiative transfer for optically shallow waters with benthic substrates colonized by submerged aquatic vegetation (SAV). Such models will enable the quantitative prediction of upward spectral radiation from vegetated seabeds, permitting the use of optical remote sensing to search for submerged objects of anthropogenic origin and for rapid mapping of submarine resource distribution and abundance in coastal waters. These models will also have important applications for predicting irradiance levels within SAV canopies, a task necessary for accurate determination of light requirements and photosynthetic productivity of these ecologically important organisms.

YEAR 1 OBJECTIVES

First-year emphasis was placed on (i) characterization of canopy architecture of a seagrass meadow in Monterey Bay, based on morphometric analysis of over 1000 individual eelgrass leaves, (ii) direct measures of leaf spectral absorption and reflection, and (iii) development and sensitivity analysis of coupled radiative transfer-production models of SAV canopies.

APPROACH

The work involves development of mathematical descriptions of biomass distribution, canopy architecture, light absorption and photosynthesis within SAV canopies from direct field observations and laboratory measurements. A system of coupled equations generated from these measurements was solved for specific scenarios of canopy structure and water column optical properties to evaluate the effect of spectral quality and flux density of the downwelling irradiance on whole canopy productivity. Radiative transfer within the canopy is based on the simple model first proposed by Monsi and Saeki (1953) which provides an excellent first-order description of radiation interception within closed (horizontally homogeneous) canopies (Norman and Welles 1983). A spectral photosynthesis model, based on the leaf absorption and reflection data, was developed for comparison to more traditional scalar calculations of photosynthesis under a range of canopy architectures and water columns with different inherent optical properties.

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WORK COMPLETED

In the first year, canopy architecture of the eelgrass meadow growing at Del Monte Beach, Monterey, California, was characterized from measures of leaf length, width, leaf density per shoot and shoot density per m^2. From these data, a preliminary model of vertical canopy architecture (biomass distribution) was developed (Zimmerman and Mobley 1997a; b) and later expanded to include the effect of flow on canopy architecture, (Zimmerman and Mobley 1997c; Maffione and Zimmerman submitted; Zimmerman and Maffione submitted). Scalar irradiance distributions generated by the simple model were used to drive a density-dependent model of eelgrass productivity (Zimmerman and Mobley 1997 a; b). The model was expanded to include leaf spectral absorption and reflection modeled as a sum of gaussian curves that accurately reproduced laboratory-measured spectra. The spectral model of leaf absorption was incorporated into the canopy architecture model, allowing prediction of spectral irradiance distribution down through the canopy. A spectral model of photosynthesis, based on light absorption was developed and its predictions compared to a more traditional approach based on scalar irradiance (Zimmerman, et al. 1994; Zimmerman and Mobley 1997a; b; c). The radiative transfer model *Hydrolight* (Mobley 1989) provided irradiances for the top of the leaf canopy as a function of season, time of day, water clarity (phytoplankton concentration) and water depth. Light was attenuated through the canopy as a function of biomass density and leaf spectral absorbance. Production was then calculated from the absorbed irradiance using both spectral and scalar photosynthesis models and compared to daily respiratory demand of whole plants (Zimmerman et al. 1996; 1997) to calculate ratios of daily production to respiration (P:R).

RESULTS

The absorption spectrum of eelgrass leaves results chiefly from chlorophylls *a* and *b*, the dominant photosynthetic pigments in this submerged angiosperm. Consequently, the spectral distribution of irradiance became increasingly peaked in the green region (500-600 nm) as light was propagated through the canopy in the model (Fig. 1; Zimmerman et al. submitted; Zimmerman and Mobley 1997c; Zimmerman and Maffione 1997; Maffione and Zimmerman submitted).

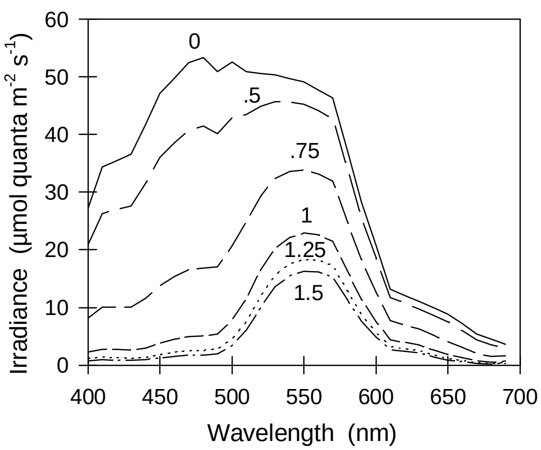

Figure 1. Calculated irradiance spectrum at indicated depths within a 1.5 m tall model eelgrass canopy.

With irradiance spectra characterized by high photon fluence rates and a large proportion of blue light relative to green, (i.e. blue waters), the spectral and scalar irradiance models produced identical profiles of canopy production (Zimmerman and Mobley 1997c; Zimmerman and Maffione 1997; Zimmerman and Maffione submitted). The models diverged, however as irradiance entering the top of the canopy declined, as shoot density increased, or when the ratio of blue light (440 nm) to green light (550 nm) dropped below 0.3 (Fig.2). Predicted values of daily production from the spectral and scalar models proved to be quite different under such conditions. The daily integral of the instantaneous noon profile presented in Fig. 2 for the mechanistically accurate spectral production model was 40% lower than the commonly used scalar calculation. More importantly, the two models give clearly different impressions regarding the suitability of the modeled light environment for sustained long term survival of the eelgrass population. The spectral model indicated the light environment is barely adequate for positive daily carbon balance (defined as P:R > 1), and long term survival while the scalar model suggested light availability to be well in excess of that required for long term survival.

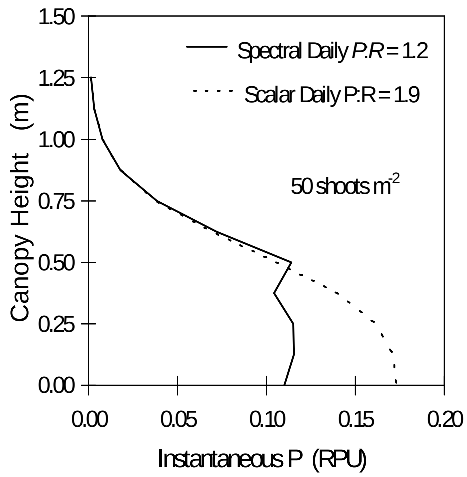

Figure 2. Vertical profiles of instantaneous noon production through the model eelgrass canopy with a green-dominated (E_{440}:E_{550} = 0.28) spectrum.

The spectral model was also used to explore the impact of seasonal variations in light availability on sustainable shoot density (Zimmerman and Mobley 1997c). As in the above examples, spectral irradiance at the top of the seagrass canopy was calculated using *Hydrolight* for a 5.5 m water column during summer and winter. Water column IOPs were held constant, but sun angle and day-length were altered to reflect seasonal extremes at the latitude of Monterey Bay (36°N). The model predicted summer conditions should allow maintenance of positive carbon balance at shoot densities up to 150 m^{-2}, while winter should produce severe light limitation at densities well below maximum sustainable levels calculated for summer. Thus, long-term survival may depend on severe shoot thinning during winter months to reduce the effects of canopy shading and/or accumulation of internal carbon reserves during summer months to sustain shoots during light-limited periods.

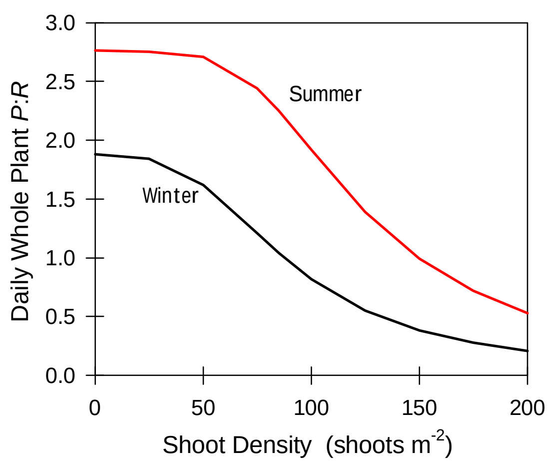

Figure 3. Daily whole-plant P:R plotted as a function of shoot density for winter and summer irradiance conditions.

Taken together, the model calculations performed to date indicate that scalar PAR may severely overestimate light available for photosynthesis of SAV in most coastal environments where the water column is characteristically turbid and the irradiance spectrum is dominated by green light (500 - 600 nm).

IMPACT/APPLICATIONS

The results outlined here provide the first steps toward construction of a full radiative transfer model for remote sensing applications in coastal waters that includes highly variable bottom topography colonized by submerged aquatic vegetation. This approach will improve our ability to understand and interpret remote sensing imagery from coastal waters for a variety of applications, including the search for and identification of anthropogenic targets, and environmental resource monitoring programs.

The results produced to date also have serious implications for environmental agencies charged with managing and monitoring coastal water quality. Measures of scalar PAR may provide misleading information with regard to quality of the habitat for SAV and benthic productivity in turbid coastal waters containing significant amounts of suspended particles, phytoplankton and colored dissolved organic material, particularly where light environments are already marginal and SAV are most threatened.

TRANSITIONS

This work has attracted considerable attention from seagrass management agencies and other scientists interested in coastal water quality. Theoretical calculations on the effects of sediment loading on the submarine light environment and seagrass photosynthesis, performed in collaboration with R. Maffione, were presented at a workshop sponsored by the US Army Corps of Engineers Waterways Experiment Station. The Army Corps is now re-thinking their plans for monitoring coastal environments and evaluating the effects of dredging operations on coastal SAV populations to include spectral irradiance as a result of our work. In particular, this has already led to the modification of a dredge monitoring program in Laguna Madre, Texas to include measures of spectral backscattering and irradiance, under the supervision of R. Maffione.

RELATED PROJECTS

The efforts described above are being performed in collaboration with R. Maffione (separately funded by ONR) to produce measurements of light field characteristics within and above seagrass meadows and to develop more realistic light field models for SAV canopies. The observed data will be compared to model calculations as part of the closure experiment fundamental to the CoBOP program. C. Mobley (separately funded by ONR) is calculating in-water irradiance profiles with *Hydrolight* for input to the canopy model.

I have just begun a new collaboration with Eva-Marie Koch (Horn Point Laboratory, University of Maryland) and Heidi Nepf (MIT) to include the effects of water motion and mechanical turbulence in the seagrass production model. We plan to submit a proposal to NSF to support continued development of this collaborative effort.

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